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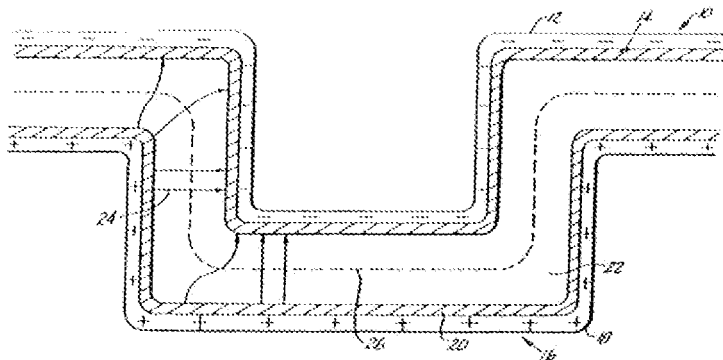
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(54) Title: METHOD AND APPARATUS FOR ENERGY PRODUCTION USING COLD NUCLEAR FUSION WITH A
LITHIUM DEUTEROXIDE ELECTROLYTE

(57) Abstract

The present invention enables nuclear fusion of deuterons and lithons. A crystalline lattice (14) having octahedral interstitial sites aligned with an electrical field (24) is exposed on a first surface to a electrolytic solution of heavy water and lithium deuteride contained in a channel (22). Deuterium and lithium atoms from the electrolyte are absorbed into the crystalline structure where their electrons are stripped to produce deuterons and lithons, the latter retaining two electrons. Under the influence of the electric field, deuterons tunnel through the lattice and collect in interstitial sites to provide a palladium deuteride lattice (the β phase of palladium). A barrier, which may comprise an electrode (12) on which the crystalline lattice is deposited, is introduced which terminates the lattice perpendicular to the electric field to preclude further tunneling or diffusion of the deuterons from the interstitial sites adjacent the barrier. Heating of the electrolytic solution enhances the overlap of the energies of the diffusing particles with transmission resonance energy levels specific to the metal deuteride lattice and the particles diffusing through it. This promotes the diffusion of deuterons and lithons from the electrolyte into the lattice increasing the probability of fusion reactions between diffusing particles and the deuterons already in the lattice interstitial sites. Heat generated from the fusion reactions is extracted from the crystalline lattice and employed for power generation.

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10 METHOD AND APPARATUS FOR ENERGY PRODUCTION
 USING COLD NUCLEAR FUSION
 WITH A LITHIUM DEUTEROXIDE ELECTROLYTE

Cross-Reference to Related Applications

15 This is a continuation-in-part of prior U.S. Patent
Application Serial Number 07/352,853, filed on May 15,
1989, in which a method and apparatus employing a
crystalline palladium lattice for the production of energy
using cold nuclear fusion is described in detail and
20 incorporated herein by reference.

Field of the Invention

 The present invention relates generally to production
of power through the use of a steam turbine system
25 receiving heat energy from a nuclear fusion reactor. More
particularly, the invention provides a
crystalline/palladium lattice reactor aligned in an
electric field to receive deuterons into interstitial
lattice sites from a deuterium source. The crystalline
30 lattice is blocked perpendicular to the electric field in
the lattice at a given depth preventing migration of
deuterons out of the lattice. The crystalline lattice is
immersed in a heavy water electrolyte solution containing
lithium deuterioxide (LiOD). A heater maintains the
35 electrolyte solution at an elevated temperature to
increase the number of transmission resonance levels
available for deuteron and lithium diffusion in the

1 lattice. Use of a high purity of Li^6 isotopes in the
lithium deuterioxide enhances the reactor by reducing the
probability of tritium production. Heat energy generated
in the fusion is conductively transferred to a liquid
5 coolant system and steam driven turbines for power
generation.

Background of the Invention

Basic concepts for the generation of energy through
10 nuclear fusion have centered on the so-called "hot" fusion
approach. In "hot" fusion, deuterium atoms are forced
together under great pressure and temperature sufficient
to provide energy to overcome the Coulomb repulsion force
and drive together the nuclei of the deuterium atoms to
15 fuse. The result is nuclear fusion to produce an He^3
nucleus plus a neutron or a tritium nucleus plus a proton.
Temperatures of 10^8 degrees K are required to provide
sufficient energy to overcome the Coulomb barrier of the
deuterons.

20 In a palladium lattice loaded with deuterons, a β
phase of palladium is produced which may significantly
increase the probability for nuclear reactions between
deuterons diffusing through the lattice and the deuterons
fixed in the lattice producing the β phase. It has been
25 suggested by L. Turner in his letter to the editor
published in Physics Today, 1989, pp. 140-141, that cold
fusion may involve transmission resonances for deuterons
diffusing through a periodic array of wells formed by the
Coulomb barriers of the deuterons sitting at the
30 interstitial sites. The resonance condition of

$$\int \kappa(x) dx = (n + 1/2) \pi$$

will provide a transmission coefficient of unity if
35 satisfied by the wave number of the particle crossing the
potential well between two neighboring barriers where $\kappa(x)$

1 is the wave number of the diffusing particle. A
transmission resonance condition may be hypothesized as

$$(2n + 1) \lambda/4 = L$$

5

where $n = 0, 1, 2 \dots$. λ is the de Broglie wavelength
of the diffusing deuteron and L is the width of the well
in the array. Electron screening of the deuterons by the
palladium lattice will make the wells shallower than
10 normal. Transmission will, therefore, occur for a
diffusing deuteron whenever an odd number of quarter
wavelengths of the deBroglie waves fit into the well
width. Bohm has noted in Quantum Theory, Prentice-Hall,
Inc., Englewood Cliffs, New Jersey, 1951, p. 287, that "it
15 is especially interesting that although a single high and
thick barrier has a very small transmissivity, two such
barriers in a row can be completely transparent for
certain wavelengths. This barrier can be understood only
in terms of the wave-like aspects of matter. The high
20 transmissivity arises because, for certain wavelengths,
the reflected waves from inside interfere destructively
with those from outside so that only a transmitted wave
remains."

As also shown by Bohm, the resonance condition also
25 expresses the condition for existence of metastable or
virtual states associated with wells having barriers.
These states are unbounded and have a relative long
lifetime due to the fact that deBroglie waves associated
with the deuterons reflect back and forth in the well many
30 times before the barrier is penetrated. The energies of
these states may be found by combining the transmission
resonance condition equation with the following well known
relations:

35

$$E = p^2/2m \text{ and } \lambda = h/p,$$

1 where p is the momentum of the diffusing deuteron and m
is its mass. Combining these equations yields the
metastable state energies:

5
$$E_n = (2n + 1)^2 h^2 / 32m L^2.$$

Since these energies are based on the resonance condition
to achieve transmission, these are also the energies for
the transmission resonances.

10 If occupation of a metastable state is proportional
to the Boltzmann factor:

$$\exp (-E_n/kT),$$

15 where k is the Boltzmann's constant and T is the
temperature in Kelvin, the energies may be expressed in
terms of temperatures T_n ,

$$E_n = kT_n.$$

20

The Boltzmann factor may then be rewritten:

$$\exp (-T_n/T).$$

25 Substituting for the energy E_n , we find

$$T_n = (2n + 1)^2 h^2 / 32mkL^2.$$

30 This equation indicates the temperature relationship for
resonance levels associated with the widths, L , of the
wells in the array produced by the lattice as previously
described.

35 An apparatus designed by Pons and Fleischmann has
been reported in an article (see Fleischmann, M. and Pons,
S., "Electro-chemically Induced Nuclear Fusion of
Deuterium", submitted to Journal of Analytical Chemistry,
March 20, 1989). The apparatus which was employed to

1 obtain the fusion reported in this paper was embodied in
several forms. In a first embodiment, a palladium rod
cathode and an encircling helical platinum anode were
5 inserted in a heavy water (D_2O) electrolytic solution
connected with a potential providing a maximum current
density of approximately 512 mA/cm^2 . In an alternative
configuration, a rectangular palladium sheet cathode was
surrounded by a platinum sheet anode and operated in the
heavy water electrolyte with current densities of
10 approximately 1.6 mA/cm^2 . With both configurations,
evidence of nuclear fusion was reported. However, methods
and apparatus to obtain consistent power generation with
controllability of the fusion reaction and necessary
reliability are unknown.

15 Nuclear effects have also been noted by H. O.
Menlove, M. M. Fowler, E. Garcia, A. Mayer, M. C. Miller,
R. R. Ryan, and S. E. Jones, as noted in a presentation
to the Workshop on Cold Fusion Phenomena, May 23 through
25, Santa Fe, New Mexico, entitled "The Measurement of
20 Neutron Emissions from $Ti + D_2$ Gas". Neutron emissions
were noted from titanium shavings pressurized with D_2 gas
cooled to liquid nitrogen temperature and warmed to 243
K. Similar nuclear effects were seen in the Cassacia
experiment reported by A. DeNinno, et al., in a
25 presentation at the Workshop on Cold Fusion Phenomenon,
May 23 through 25, Santa Fe, New Mexico, entitled "Neutron
Emission from a Titanium Deuterium System", in which
titanium blades were heated at 1,273 K in the presence of
0.1 mbar of D_2 gas, followed by lowering of the
30 temperature to 773 K at 20 mbar D_2 . Neutron emission was
observed after reheating of the sample to 1,273 K. Again,
however, methods and apparatus to obtain consistent power
generation with controllability of the reaction present
were not disclosed.

1 Summary of the Invention

 The present invention provides a method and apparatus
for obtaining heat energy from cold fusion. A palladium
crystalline lattice provides a containment structure for
5 deuterons in the octagonal interstitial sites of the face
centered cubic structure. Deuterons with sufficient
energy will migrate through a uniform palladium lattice
by tunneling through the covalent bond barriers of the
lattice. By alignment of an electric field with the
10 $\langle 1,1,0 \rangle$ direction of the palladium lattice diffusion of
the deuterons through the lattice is enhanced. To
preclude diffusing particles from transitioning completely
through the lattice, a means for blocking further
tunneling is provided.

15 In a presently preferred embodiment, the palladium
lattice is structured as a plurality of single crystal
rods with the $\langle 1,1,0 \rangle$ direction of the individual lattice
sites in the rods perpendicular to a first surface of the
crystal. The first surface of the crystal is exposed to
20 a source of deuterium atoms, such as a heavy water
electrolyte solution, to provide a source of deuterons.
The blocking member interfaces the crystalline lattice on
another surface of the crystal perpendicular to the
electric field to prevent tunneling of the deuterons
25 completely through the crystal. Preferably the blocking
member is a metallic structural member. The combination
of the palladium crystal and the metallic member may
operate as a cathode in an electrolytic cell.

 An electrolytic solution containing lithium
30 deuterioxide (LiOD) to provide lithium ions (lithons) and
deuterium ions (deuterons) is employed in the cell.
Deuterons diffusing into the palladium lattice create a
 β phase in the palladium which allows enhanced
transmission of lithons and deuterons into the palladium
35 deuteride lattice. The lithons and deuterons react in the
lattice in a cold fusion process producing heat energy.

1 By employing high purity Li^6 isotopes in the lithium
deuterioxide electrolyte, production of tritium is avoided
thereby providing a "clean" reactor.

5 Configuration of the cathode as a structural dividing
member allows containment of the electrolytic solution on
the crystal surface of the cathode with circulation of a
coolant fluid on the opposite side of the cathode to
transport away heat generated by the fusion process in the
10 lattice. A complementary anode structure of appropriate
materials provides a second wall for the electrolyte
container. Sealing between the edges of the electrodes
with appropriate nonconductive material, such as quartz,
completes the electrolyte container.

15 A heater is provided for the electrolytic solution
to elevate the temperature for enhancement of transmission
of the lithons and deuterons into the lattice by making
more transmission levels in the palladium deuteride
lattice available. Initiation of the fusion reaction is
assisted by elevating the temperature of the electrolyte
20 after loading of the palladium lattice with deuterons to
achieve a β phase.

25 The potential applied across the electrodes is
defined incrementally in magnitude by the desired
transmission wavelength of the lithons and deuterons. The
rate of the fusion process can be controlled by current
density within the electrolytic cell. A larger forward
current will increase power by accelerating tunneling of
the lithons and deuterons in the lattice, while a reverse
current will reduce tunneling in the lattice, shutting
30 down the fusion reaction.

1 Brief Description of the Drawings

 The preferred embodiment of the invention is shown in the drawings.

5 FIG. 1 is a top cross-sectional view of the electrolytic cell;

 FIG. 2 is a pictorial representation of the palladium lattice.

 FIG. 3 is a pictorial sectional view of the elements of the electrolytic cell;

10 FIG. 4 is a pictorial schematic diagram of the reactor core;

 FIG. 5 is a schematic diagram of the reactor power plant;

15 FIG. 6 is a side cross-sectional view of one embodiment of the electrodes of the electrolytic cell employing a plurality of rods of palladium crystal;

 FIG. 7 is a representation of the resonant transmission temperature levels for a PdD lattice;

20 FIG. 8 is a graph of the dimensionless power factor for the palladium deuteride lattice; and,

 FIG. 9 is a graph of the temperature rate of change of the power factor.

25

30

35

1 Detailed Description

Referring to FIG. 1, two electrodes are shown. The first electrode 10 comprises a metallic structural member 12 with a palladium cladding 14. The structural member is configured in a corrugated pattern having multiple parallel channels for structural support and fluid cooling as will be described in greater detail subsequently. A second electrode 16 comprises a structural metallic member 18 with a cladding 20 of platinum or other nonreactive metal. The second electrode has a complementary shape to the first electrode and is mounted in spaced relation to the first electrode, creating a contained channel 22 between the two electrodes. This channel contains an electrolytic solution with purified heavy water (D_2O) and lithium deuterioxide ($LiOD$), or other metal deuterioxide which will be described in greater detail subsequently. A purity of 99.5% D_2O for the water in the electrolytic solution is preferred. Application of an electric potential across the two electrodes creates an electric field represented by field lines 24. The field will be perpendicular to the surface of each electrode. As is typical of electrolytic cells, deuterium gas will be evolved at the surface of the cathode, while oxygen gas will evolve at the surface of the anode. A spun quartz fiber screen 26, which bisects the channel between the electrodes, is employed to prevent mixing of the deuterium and oxygen gases as they rise to the top of the channel where they are vented into separate collection reservoirs, as will be subsequently described.

30 The palladium cladding on the cathode is arranged to provide a crystalline lattice of palladium having a significant plurality of the individual cells of the lattice each oriented with a $\langle 1,1,0 \rangle$ direction parallel to the electric field at the electrode surface as well as the interior of the lattice. This condition is achieved by methods to be described in greater detail subsequently. As shown in FIG. 2 for a face centered cubic lattice 210,

1 the individual atoms 212 are joined by covalent bonds 214.
The direction of view in FIG. 2 is along a $\langle 1,1,0 \rangle$
direction of the lattice. An electric field perpendicular
to the electrode surface as shown in FIG. 1 is therefore
5 perpendicular to the interstitial sites in each lattice
cell through the associated covalent bonds. The
arrangement of atoms in the lattice provides an octahedral
interstitial site cornered by the atoms and bounded on
each side by covalent bonds. Deuterium atoms adsorbed on
10 the surface of the crystal lattice are drawn into the
interior of the lattice by the electric field. As the
deuterium atoms enter the electrode's interior they are
stripped of their electrons. These electrons move into
the Palladium conduction band and become delocalized from
15 the deuterium nucleus, or deuteron. The deuteron is then
acted on by the electric field and drawn through the
lattice until a physical barrier is encountered which
cannot be tunneled through or diffused around by the
deuteron.

20 The stripping of the electron from the deuterium atom
in effect transforms a fermion (the deuterium atom) into
a boson (the deuteron).

The potential between the electrodes is established
to provide an electric field for loading of the lattice
25 having a magnitude to excite the deuteron wavelength for
transitioning through the covalent bonds of the
crystalline lattice. For this effect the deuteron
wavelength is described by the equation: $(\lambda) = 4L/n$, where
L is the distance across the octahedral sites in the
30 lattice (approximately two Angstroms in palladium), and
n is an odd integer. The addition of an AC ripple signal
may be employed to tune the field for appropriate deuteron
wavelength.

35 The barrier is placed perpendicular to the electric
field, which is the preferred direction of migration of
the deuterons. In some configurations, the barrier may
interface with the crystal on more than one plane to block

1 deuterons driven by components of the electric field
parallel to more than one of the $\langle 1,1,0 \rangle$ directions of the
lattice.

5 The electric field in the electrode itself is
determined in part by the physical connection of the
electrode to the electrical potential. The electrical
field in the palladium cladding in the preferred
embodiment is maintained substantially perpendicular to
10 the surface of the cladding by the use of a metallic
support having high conductivity and significant depth
dimension with respect to the cladding. In addition, as
the deuterium atoms diffuse into the palladium cladding,
the resistance of the cladding increases. The net effects
15 of the physical geometry of the support and the increased
resistance of the palladium cladding is the displacement
into the metallic support of the majority of current flow
to the potential. Consequently, the electric field in the
palladium cladding remains essentially perpendicular to
the surface of the electrode and the cladding.

20 If enhancement of the direction of the electric field
in the cladding is required, strips of insulator may be
added to the surface of the palladium cladding, extending
into the cladding perpendicular to the surface and to the
direction of net current flow to the potential.
25 Channeling of current perpendicular to the surface
accomplished by the insulating strips enhances the field
perpendicular to the surface.

30 An embodiment of this form is shown in FIG. 6 in
which long single crystals 610 are laminated between
insulating strips 612 onto a polycrystalline cladding 614.
The single crystals have a $\langle 1,1,0 \rangle$ axis parallel to the
electric field which is forced to remain in a direction
perpendicular to the electrode surface all the way through
the single crystal.

35 These long single crystals may be grown using a
floating zone electron beam method. Polycrystalline rods
of 4 - 5 mm in diameter are bombarded with an electron

1 beam in a vacuum environment of 10^{-5} to 10^{-6} Torr. The
beam melts a region of the rod approximately equal to the
diameter in length. The heated section of the rod
recrystallizes as a single crystal. The rod is then
5 advanced and a new length bombarded by the beam similar
to a zone refining process. Details of the process may
be found in Pamplin, B.R., Crystal Growth, Pergamon Press
(1975) PP 140 -142. Impurities are evaporated during this
process, further enhancing the crystal.

10 The polycrystalline cladding in the embodiment shown
in FIG. 6 is silver or other nonreactive metal having a
higher thermal conductivity than palladium and a smaller
crystalline structure to provide a deuteron diffusion
barrier.

15 In each of the embodiments described, the structural
member provides the electrical contact in addition to a
barrier to diffusion and tunneling of the deuterons in the
palladium cladding perpendicular to the surface of the
electrode. As previously described, the electric field
20 direction in the cladding layer is substantially
perpendicular to the surface of the layer, resulting in
the structural support being perpendicular to the field
to provide an effective barrier for the deuterons.

Referring now to FIG. 3 the preferred configuration
25 of the electrodes is suitable to provide a self-contained
electrolytic cell. The corrugated shape of the cathode
10 and complementary shape of the anode 16 when placed in
spaced relation provide two sides of an enclosure for the
heavy water electrolyte of the cell. Sealing at the
30 peripheral extremities of the electrodes may be
accomplished by a insulating quartz cap 310 employing
quartz to metal seals 312 at the cathode and anode.
Similar insulating quartz caps may be employed at the
upper and lower boundaries of the electrodes with
35 appropriate connections for introducing the electrolytes
and withdrawing the evolved gases.

1 As shown schematically in FIG. 4 multiple cells 410
may be placed in a common pressure vessel 412. The
electrolyte is supplied to each of the cells through
connection 414. Deuterium and oxygen gas evolved at the
5 surfaces of the electrodes in each cell are scavenged
through connections 416 and 418, respectively. As
previously described with respect to FIG. 1, a spun quartz
fiber screen or other appropriate device may be employed
to prevent mixing of the deuterium and oxygen gases in the
10 electrolytic cells.

Coolant is introduced to the pressure vessel at
connection 420 and circulated through the channels formed
by the electrodes external to the electrolytic cell.
Withdrawal of the circulating coolant is accomplished at
15 connection 422. In the embodiment shown high purity
ordinary water (H_2O) is used as the coolant. Appropriate
corrosion protection steps for the structural members of
the electrodes exposed to the coolant must be employed to
prevent degradation of the electrodes.

20 The circulating coolant provides the heat exchange
medium for withdrawing energy from the reactor which is
created by fusion in the palladium reactor lattices of the
cathodes in the electrolytic cells. An embodiment
employing standard steam plant operating parameters
25 provides an operating temperature of 650°C. This results
a factor of approximately two for safety margin to the
melting temperatures of materials employed in the
electrolytic cells and reactor pressure vessels (steel
1600°C, nickel 1455°C, palladium 1549°C, platinum 1773°C,
30 copper 1100°C).

Operation at 650°C requires pressurization above
2200psi to prevent boiling in the system. The coolant
loop in the reactor and the heavy water electrolyte are
therefore maintained above 2200psi.

35 FIG. 5 provides a schematic for an embodiment of a
power generation system employing the reactor of FIG. 4
and a dual coolant loop power generation system. A heavy

1 water electrolyte tank 510 stores the electrolyte which
 is pumped to the electrolytic cells through a first feed
 pump 512 to the pressure vessel. The evolved oxygen and
 5 deuterium gas from the electrolytic cells are stored in
 tanks 514 and 516, respectively. Liquefaction of the
 gases may be employed to reduce storage volume. The
 primary coolant loop provides cooling water through a
 second pump 520 to the pressure vessel. Coolant exiting
 10 the pressure vessel is routed through a heat exchanger 522
 and returned to the pump 520. A secondary coolant loop
 employing water or other appropriate coolant receives heat
 in the heat exchanger to generate power in the turbine 524
 after which it is condensed in condenser 526 and returned
 to the heat exchanger by a third pump 528.

15 The present invention also controls the temperature
 of the electrolytic solution. The temperature
 relationship

$$T_n = (2n+1)^2 h^2 / 32mkL^2$$

20 provides a basis for hypothesizing the transmission
 resonance level spectrum for a palladium deuteride (PdD)
 lattice. From the experimental evidence of Pons and
 Fleischmann previously described, transmission resonance
 25 is present at room temperature (293K). By solving for the
 well width for $T_n = 293K$ we find

$$\begin{aligned} L_n &= (2n+1) (0.349\text{\AA}) (243K/293K)^{1/2} \\ &= (2n+1) (0.318\text{\AA}) \end{aligned}$$

30 Therefore, for integers 0,1,2,3,4, etc. the following well
 widths are defined

$$0.318\text{\AA}, 0.953\text{\AA}, 1.59\text{\AA}, 2.22\text{\AA}, 2.86\text{\AA}, \text{ etc.}$$

35 The lattice parameter for Pd in the α phase is well known
 to be 3.89Å. It is also known that the lattice undergoes

1 a uniform 11% expansion to reach the β phase. Therefore,
the new lattice parameter is given by $3.89\text{\AA} \times (1.11)^{1/3}$.
The separation of two deuterons residing at neighboring
octahedral interstitial sites is the value of the lattice
5 parameter divided by $(2)^{1/2}$ or 2.85\AA .

Selecting the width of the a well formed by the
ascending Coulomb barriers of neighboring deuterons in the
lattice as 2.86\AA a temperature level scheme for
transmission resonance levels may be obtained for a
10 deuterium loaded β phase palladium lattice with deuterons
as the diffusing particles (diffusons).

$$T_n = (2n+1)^2 (27\text{K}) (1.047\text{\AA}/2.86\text{\AA})^2 \\ = (2n+1)^2 (3.62\text{K})$$

15

FIG. 7 portrays this level scheme.

A temperature width, ΔT_n , is present at each level.
 ΔT_n is associated with the variation in the well width
due to thermal vibration. This may be characterized as
20 phonon exchange between the deuterons responsible for the
Coulomb barrier wells and the metal lattice. This
variation, ΔL , in the well width due to vibration from
the level T_n may be estimated by

$$25 \quad (1/2)m \omega^2 (\Delta L)^2 = (1/2)kT$$

therefore,

$$\Delta L = (kT/m \omega^2)^{1/2}.$$

30

Then,

$$\Delta T_n = 2(\Delta L/L) T_n.$$

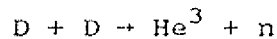
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These level widths provide transmission bands for
propagation of the deuterons in the lattice. Transitions
via phonon exchange with the lattice would become

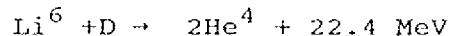
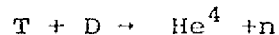
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1 significant whenever the thermal energy kT associated with
 an "average" phonon becomes of the order of kT_n , i.e. when
 $T=T_n$. Neutron emissions may be created by transitions of
 diffusing deuterons between levels. The burst nature of
 5 these emissions may associated with the boson nature of
 neutrons since the symmetric wave function gives bosons
 the tendency to be "gregarious".

The deuterium reactions in the lattice may be



The following nuclear reactions may also be catalyzed from
 15 the system using the LiOD and heavy water electrolyte via
 the transmission resonances within the lattice:



Reactions of Li^7 to produce tritium may also be present.

25 The Li^6 - on - a - deuteron reaction to produce He^4
 is hypothesized as the primary energy producing reaction
 in the present invention. Again solving for the well
 width in the lattice, now for Li^6 diffusons in a PdD
 lattice, we see

30
$$L_n = (2n+1)(0.1838\text{\AA})$$

This generates widths of

35 $0.18\text{\AA}, 0.55\text{\AA}, 0.92\text{\AA}, 1.29\text{\AA}, 1.65\text{\AA},$

$2.02\text{\AA}, 2.39\text{\AA}, 2.76\text{\AA}, 3.12\text{\AA}, \text{ etc.}$

1 Again employing the width closest to that of 2.85Å
characteristic of the PdD lattice, 2.76Å, we obtain

5
$$T_n = (2n+1)^2 (1.303K)$$

resulting in levels of

10
$$1.3K, 11.7K, 32.6K, 63.8K, 105.5K, 157.7K, \\ 220.2K, 293.2K, 376.6K, \text{ etc.}$$

For Li^7 diffusons within the PdD lattice we find

15
$$L_n = (2n+1) (0.1702\text{\AA})$$

resulting in

$$L = 2.89\text{\AA}$$

20 leading to a result for the transmissions levels
temperatures of

$$T_n = (2n+1)^2 (1.0145K)$$

25 with transmission levels of

$$1.0K, 9.1K, 25.4K, 49.7K, 82.2K, 122.8K, 171.5K, \\ 228.3K, 293.2K, 366.2K, \text{ etc.}$$

30 The presence of a transmission resonance level at
293.2K (20C) or room temperature in the deuteron, Li^6 , and
 Li^7 transmission level structures and numerous transition
levels below room temperature supports the presence of
heat producing reactions in a room temperature system.
35 Increasing the temperature of the electrolytic solution
shifts the Boltzmann distribution for the diffusons to
higher energies. This gives more overlap with the higher

1 order (greater n) transmission levels, which also have
more of a thermal width. This enhances the probability
of transmission of the diffusons with a consequent
enhancement for nuclear reactions.

5 The tunneling process ordinarily associated with a
cold fusion reaction is sensitive to the mass of the
tunneling particle. For example, R. Bush and R. Eagleton
in "Cold Nuclear Fusion: A Hypothetical Model to Probe an
Elusive Phenomenon", Journal of Fusion Energy, accepted
10 for publication August 1989, show that the transmissivity
for cold fusion not involving a metal lattice is given
approximately by

$$T = \exp\{-\alpha(m/E)^{1/2}\}$$

15 where α is a constant, m is the mass of the tunneling
particle, and E is the energy of the particle incident
upon the Coulomb barrier. For particles of equal energy
 E , the probability for tunneling decreases strongly as the
20 mass m increases. In contrast, cold Fusion within a metal
lattice such as the palladium deuteride in the present
invention can actually increase as mass increases. This
is clear from the equation for the de Broglie wavelength
of the diffusing particle

25

$$\lambda = h/(2mE)^{1/2}$$

since for particles of equal energy, E , λ is smallest for
the particle of largest mass. The advantage of smaller
30 λ is that there are more ways in which the transmission
resonance condition can be satisfied. The formula for T_n
specifying the resonant transmission levels also shows
this, since mass m occurs in the denominator. Based on
this, nuclear reactions in the PdD lattice involving Li^6
35 and Li^7 may predominate over those involving deuterons.
(Additionally, Li^6 may predominate over Li^7 since the
former are bosons while the latter are fermions.)

1 Similar calculations may be made for alternate
metallic lattices such as titanium which may be used for
electrode materials. Titanium deuteride as a lattice does
not provide the large number of transmission resonance
5 levels present in palladium deuteride for the same
temperature with deuterons as the diffusons. However,
structural or other considerations may make the use of a
titanium lattice in the cathode desirable with an
alternate diffuson.

10 Enhancement of the transmission resonance levels
available for the deuterons is accomplished in the present
invention by heating the electrolyte entering the reactor
in a feed water heater 530 as shown in FIG. 5. The heater
is operated to achieve electrolyte temperatures of 500 to
15 600 C to provide the greatest number of transmission
resonance levels for the deuterium and Li^6 in the
electrolyte to be transmitted through the lattice.

Electrical resistance heating, fuel fired heat
exchangers or other methods may be used for the feedwater
20 heater. Recombination of the O_2 and D_2 gases produced by
the cell may be used for the fuel heat source or as an
energy supplement for the feedwater heater by returning
the gases to the heater shown schematically by lines 532
and 534 in FIG. 5.

25 The use of high purity Li^6 for the LiOD in the
electrolyte provides a "clean" reactor avoiding production
of tritium from Li^7 . An optimum electrolytic solution
having .1 to .5 molar LiOD with a purity of 99.5% for Li^6
is used.

30 A power factor $P(T)$ is used to compare the
transmission aspects of the reactions in the present
invention. $P(T)$ is proportional to the total number of
diffusing deuterons and therefore is equal to the number
of deuterons in metastable states. The population of
35 deuterons in the n th state is proportional to the
Boltzmann factor therefore

$$\begin{aligned}
 1 \quad P(T) &= \sum \exp(-E_n/kT) \\
 &= \sum \exp(-T_n/T).
 \end{aligned}$$

5 The value of $P(T)$ increases with increasing temperature T due to the negative exponentials. A positive temperature coefficient for the cold fusion process is therefore present. A plot of the power factor for palladium deuteride is shown in FIG. 8.

10 Similarly, if it is assumed that all other aspects such as nuclear cross-sections remain the same at different temperatures the rate of change of the power factor with temperature follows directly

$$15 \quad dP/dT = T^{-2} [\sum T_n \exp(-T_n/T)].$$

A plot of dP/dT is shown in FIG. 9 for palladium deuteride.

20 The rate of change of the dimensionless power factor with temperature has an inverse square dependence upon the temperature. Similar calculations may be made for a Titanium deuteride lattice.

25 Near the surface of the electrode the diffusion of the deuterons (and other particles) in the lattice may be described in terms of the Maxwell velocity distribution for a temperature T .

$$dN(v)/dv = T^{-3/2} v^2 \exp(-mv^2/2kT)$$

30 where N is the number of diffusing particles with velocity v . A velocity v_n corresponding to a transmission resonance is given by

$$v_n = h/m \lambda$$

35 where the de Broglie wavelength λ satisfies the resonance condition. The number of diffusing deuterons having this velocity corresponding to a particular value of n is

-21-

1 proportional to the area under the curve of $dN(v)/dv$
 versus v for the value $v=v_n$. This, of course, is zero.
 Therefore, it is the phonon exchange between the lattice
 and the deuterons whose Coulomb barriers form the wells,
 5 that results in a thermal width for the resonance
 transmission levels, thus providing candidate deuterons
 for transmission. The velocity width Δv_n corresponding
 to the ΔL is given by

$$10 \quad \Delta v_n = 2 \Delta L m v_n^2 / h.$$

The relation of v_n to the n th order transmission resonance
 level is

$$15 \quad m v_n^2 / 2 = k T_n.$$

Taking the thermal width into account for the transmission
 resonance velocity, the number of candidate deuterons for
 resonant transmission is now proportional to the area
 20 under the curve of $dN(v)/dv$ versus v between $v_n - (\Delta v_n)/2$
 and $v_n + (\Delta v_n)/2$. This can be approximated by

$$\begin{aligned} ([dN(v)/dv]_v \Delta v_n) &\propto T^{-1} T_n^{3/2} \exp(-T_n/T) \\ &\propto T^{-3/2} T_n^{1/2} \Delta T_n \exp(-T_n/T) \end{aligned}$$

25

Since $([dN(v)/dv]_v \Delta v_n)$ has a maximum when $T = T_n$
 setting the derivative with respect to the temperature T_n
 equal to zero will provide a maximum:

$$30 \quad d/dT [T^{-1} T_n^{3/2} \exp(-T_n/T)] = 0$$

Solving this equation shows the maximum at

$$T_{\max} = T_n.$$

35

This also corresponds to the most probable velocity for
 the Maxwell velocity distribution. This implies that

1 neutron bursts may be produced by deuterons with
correlated velocities with the maximum of the velocity
distribution corresponding to a transmission level, v_n .

This allows a power factor of

5

$$P(T) = T^{-1} \Sigma T_n^{3/2} \exp(-T_n/T)$$

for comparing powers at different temperatures for a
particular lattice (e.g. PdD). Thus, for Li^6 lithons as
10 diffusons in a PdD lattice it can be shown that the power
yield would be three times as great at 600 K as at 293 K.
Nuclear factors should enhance this.

As a second embodiment, the growth of dendrites or
sintering of palladium grain crystals on the surface of
15 the cathode is provided to enhance a surface reaction. In
this embodiment, the structural support of the electrode
is first clad with a thin film of polycrystalline
palladium foil, or other conductive nonreactive material,
by electroplating, vapor-deposition or other technique,
20 and a layer of single crystal palladium grains is sintered
to the surface of the palladium cladding. Annealing of
the sintered grains is accomplished to create essentially
a single crystal in each grain.

A temperature coefficient based on this power factor
25 is also positive., and assuming other conditions to be the
same, more power is yielded at higher temperatures. The
Maxwell velocity distribution is shifted by increasing
temperature for higher values of v thereby allowing more
transmission levels, v_n , to make a significant
30 contribution. The thermal width, ΔT_n , of a transmission
level is proportional to both n and $T^{1/2}$.

The present invention provides opportunity for cold
fusion by loading a metal deuteride lattice and providing
diffusing particles, deuterons and lithons, with energies
35 overlapping the transmission resonance levels defined by
 T_n . Loading of the lattice is enhanced by arrangement of
the crystal lattice parallel to the electric field between

1 the electrodes and providing a barrier to prevent
diffusion completely through the lattice as previously
described. Loading of the lattice is accomplished with
a current density of about $10 - 50 \text{ mA/cm}^2$ to create a β
5 phase by loading deuterons in the interstitial sites in
the lattice. Achieving stoichiometry of at least .7 in
the reactive portion of the lattice is desirable in the
loading.

Loading is conducted with the lattice and electrolyte
10 at room temperature or lower. After loading is complete,
the probability of fusion reaction is enhanced by
increasing the electrolyte temperature using the feed
water heater. "Bumping" of the current between the
electrodes may be employed to assist in starting the
15 resonant transmission of particles into the loaded
lattice. The AC ripple previously described will be
sufficient in most applications.

As previously described control of the fusion
reaction in the individual cells is accomplished by
20 varying the current density in the electrodes thereby
controlling migration of deuterons and lithons through the
lattice to the barrier points. Variation in the
electrolyte temperature by increasing or decreasing heat
input through the feed water heater is also employed to
25 control the reaction.

Operation of the reactor will eventually "poison" the
electrodes with He^4 in the lattice. Further, the lattice
cites in which fusion has taken place and those
surrounding will be damaged due to the production of heat.
30 The electrodes in the reactor must then be refurbished or
replaced.

In operation, application of electric potential to
the reactor cells could be alternated for periodic
intervals to allow annealing of the crystalline lattice
35 or reformation of the crystal in the sites damaged by
fusion by heating from adjacent cells to effectuate "self
repair". If electrode annealing is too slow at 650°C

1 design of the operating temperature and pressure of the
reactor may be correspondingly increased as required
within limits imposed by the structural materials.

5 Reduction of pressure of the electrolyte in
combination with heating will provide some limited removal
of the He^4 in the lattice. It should be noted that
removal of the reactor electrodes and recovery of the He^4
present will provide significant cost benefit.

10 As alternative embodiments to that described
previously, the reactor lattice may be arranged on a
symmetrical electrode such as a sphere or cube where all
surfaces of the electrode exposed to the electrolyte are
perpendicular to the electric field and the field inside
15 the electrode is aligned essentially through the geometric
centroid of the electrode. Those skilled in the art will
recognize fabrication and electrical connection techniques
such as an insulated probe electrically connected at the
tip with the geometric centroid of the electrode to
20 provide the potential to the electrode. This arrangement
of all electric field lines radiating from the center of
the electrode provides a self-induced "boundary" at the
center of the electrode preventing the deuterons from
exiting the electrode. Practical heat removal in this
configuration may prove difficult.

25 It should further be noted that the reactor design
of the present invention is compatible with the structural
components of existing fission reactor designs. The
fission cores in these reactors could be replaced with the
cold fusion electrode systems of the present invention as
30 a retro-fit significantly reducing capital cost for
building such fusion reactors and providing a beneficial
use for decommissioned fission reactors in providing clean
power generation.

35 Having now described the invention in detail as
required by the patent statutes, those skilled in the art
will recognize potential modifications to the geometry and
materials employed in the electrodes including the

1 crystalline lattices and possible power generating plant
configurations without departing from the scope and intent
of the invention as described in the following claims.

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1 WHAT IS CLAIMED IS:

1. An apparatus for producing heat energy through cold fusion comprising:

5 a crystalline reactor lattice having octahedral interstitial sites defined by atoms of the lattice, and the atoms having parallel bonds on opposite sides of the octahedral sites;

 a means for maintaining an electrolytic solution including heavy water and metal deuterioxide as a source of deuterons and metal ions for diffusing particles in communication with a surface of the crystalline reactor;

 means for generating an electric field perpendicular to any pair of parallel bonds of a significant plurality of the interstitial sites, the electric field having a magnitude causing the average wavelength of the diffusing particles, between collisions, to be equal to a transmission resonance wavelength;

 means for creating a boundary which blocks the lattice perpendicular to the electric field in the lattice at a location of lower electric potential than the surface of the crystalline reactor; and,

 means for heating the electrolytic solution.

25 2. An apparatus as defined in claim 1 wherein the crystalline reactor lattice comprises a plurality of single metallic crystals of face centered cubic structure oriented in any $\langle 1,1,0 \rangle$ direction with respect to a surface of the crystal.

30

 3. An apparatus as defined in claim 2 wherein the metallic crystal is palladium.

 4. An apparatus as defined in claim 3 wherein the metal deuterioxide is lithium deuterioxide and the metal ions are lithons.

35

1 5. An apparatus as defined in claim 3 further
 comprising a structural member having a polycrystalline
 cladding to which the reactor lattice is bonded.

5 6. An apparatus as defined in claim 5 wherein the
 lattice comprises single crystal grains of palladium
 sintered to the polycrystalline cladding.

 7. An apparatus as defined in claim 4 wherein the
10 means for generating an electric field comprises:
 a cathode, the reactor lattice being an integral
 portion of the cathode;
 an anode immersed in the electrolytic solution,
 and,
15 an electric potential connected between the
 anode and cathode.

 8. An apparatus as defined in claim 7 wherein the
 electric potential is adjustable.

20 9. An apparatus for producing heat energy from cold
 fusion of diffusing particles comprising:

 an electric potential;
 a heavy water and lithium deuterioxide
25 electrolyte bath;

 a first electrode connected to the potential and
 having at least one surface immersed in the bath;

 a second electrode connected to the potential
 having at least one surface, substantially parallel to the
30 surface of the first electrode at all points of tangency,
 said one surface immersed in the bath thereby completing
 the circuit and creating an electric field in the bath and
 the second electrode further having:

 a metallic face centered cubic crystalline
35 reactor lattice exposed at the surface of the second
 electrode, with a substantial plurality of octahedral

1 interstices of the lattice oriented with the $\langle 1,1,0 \rangle$
direction perpendicular to the surface,
a metallic boundary, perpendicular to the
electric field in the second electrode, at which the
5 lattice terminates thereby preventing further tunneling
and diffusion by diffusing particles in a direction
parallel to the electric field, and,
a means for controlling the temperature of the
electrolyte.

10

10. An apparatus as defined in claim 9 wherein the
lattice terminates at a metallic boundary on each surface
not in contact with the electrolyte thereby preventing
tunneling and diffusion by the deuterons from the lattice.

15

11. An apparatus as defined in claim 9 wherein the
electric potential is controllable and reversible.

12. An apparatus as defined in claim 10 wherein the
20 crystalline reactor lattice comprises a plurality of
single crystals and the metallic boundary comprises a
structural member connected to the electric potential and
further comprising dielectric strips bonded intermediate
the single crystals to form a laminated lattice, the
25 dielectric strips perpendicular to a direction of primary
current flow in the structural member.

13. An apparatus as defined in claim 9 wherein the
electrolyte contains lithium deuterioxide having a 99.5%
30 purity of Li^6 .

14. An apparatus as defined in claim 13 wherein the
molality of the lithium deuterioxide in the electrolyte is
.1 to .5.

35

1 15. A method of producing power by fusion of
diffusing particles with trapped particles in a lattice
comprising the steps of:

 fabricating a reactor cell by the steps of
5 forming a plurality of single crystal palladium
rods having a $\langle 1,1,0 \rangle$ direction perpendicular to the
surface of the rods,

 mounting the rods to a metallic structural
member to form a first electrode,

10 placing a second electrode in parallel spaced
relation to the first electrode,

 sealing between the adjacent peripheral edges
of the first and second electrodes, and,

 introducing a heavy water and metal deuterioxide
15 electrolyte between the electrodes as a source of
deuterons and metal ions as diffusing particles,

 circulating a coolant around the reactor cell,

 applying an electric potential between the first and
second electrode,

20 controlling the polarity and magnitude of the
electric potential,

 heating the electrolyte, and,

 withdrawing heat energy from the coolant to generate
power.

25

 16. A method as defined in claim 15 wherein the
metal deuterioxide used is lithium deuterioxide and the
metal ions are lithons.

30

 17. A method as defined in claim 15 wherein the
heavy water in the electrolytic solution is 99.5% pure.

35

1 18. A method as defined in claim 15 further
comprising the steps of:

 installing a plurality of reactor cells in a pressure
vessel, and,

5 alternately applying the electric potential to
selected reactor cells to allow annealing of adjacent
reactor cells.

 19. A method as defined in claim 16 further
10 comprising the step of reducing the pressure of the
electrolyte during annealing of reactor cells to extract
He⁴ contaminant from the electrodes.

 20. A method as defined in claim 15 further
15 comprising the step of loading the palladium lattice with
deuterons to a stoichiometry of between .7 and 1 prior to
heating the electrolyte.

 21. A method as defined in claim 20 further
20 comprising the step of providing an AC ripple on the
electrode potential to bump the current in initiating a
resonant transmission of lithons and deuterons into the
lattice.

25 22. A method for creating a cold fusion reaction in
a palladium lattice electrode comprising:

 formulating a heavy water electrolytic solution
with a molality of .1 to .5 lithium deuterioxide having a
99.5% purity of Li⁶ to provide deuterons and lithons as
30 diffusing particles;

 immersing the palladium lattice in the
electrolytic solution;

 introducing an electric field of 10 to 50 mA/cm²
perpendicular to a <1,1,0> direction in the crystals of
35 the lattice to load the lattice;

1 loading the lattice to a stoichiometry of .7 to
1 with deuterons from the electrolytic solution creating
a β phase in the resulting palladium deuteride lattice;
heating the electrolytic solution to a
5 temperature exceeding a plurality of transmission
resonance temperatures for the diffusing particles; and,
controlling current in the electrode and
temperature of the electrolytic solution to control the
fusion reaction.

10

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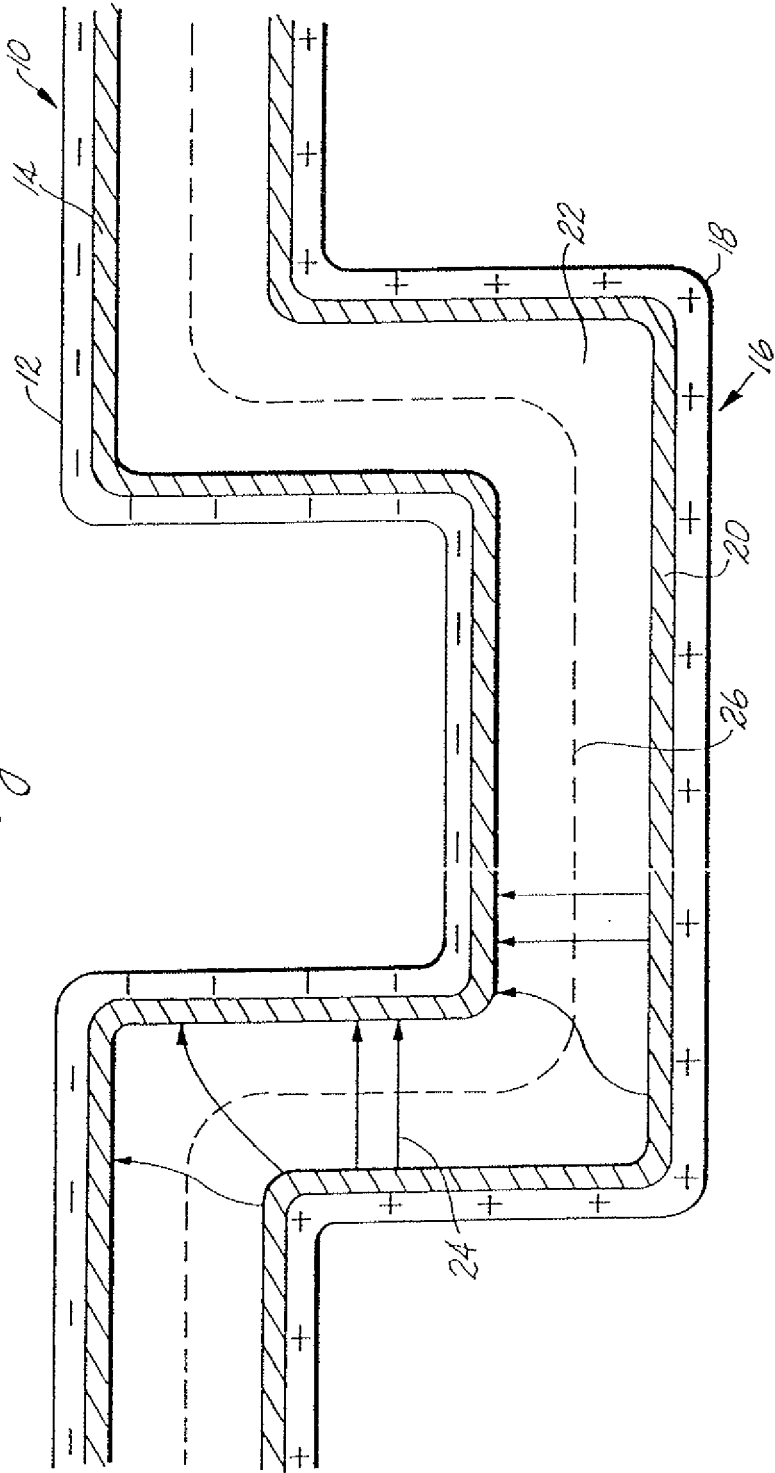
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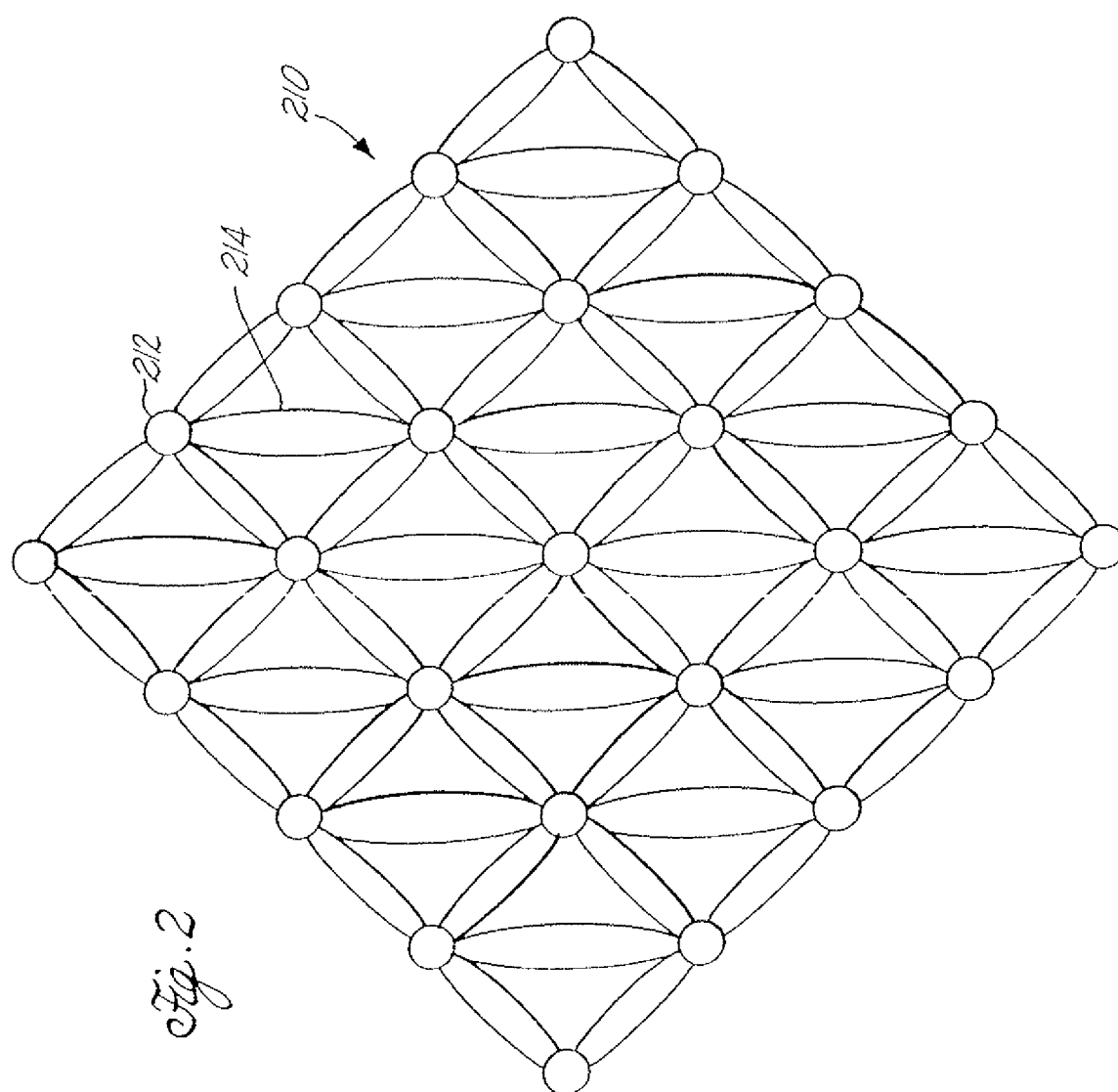
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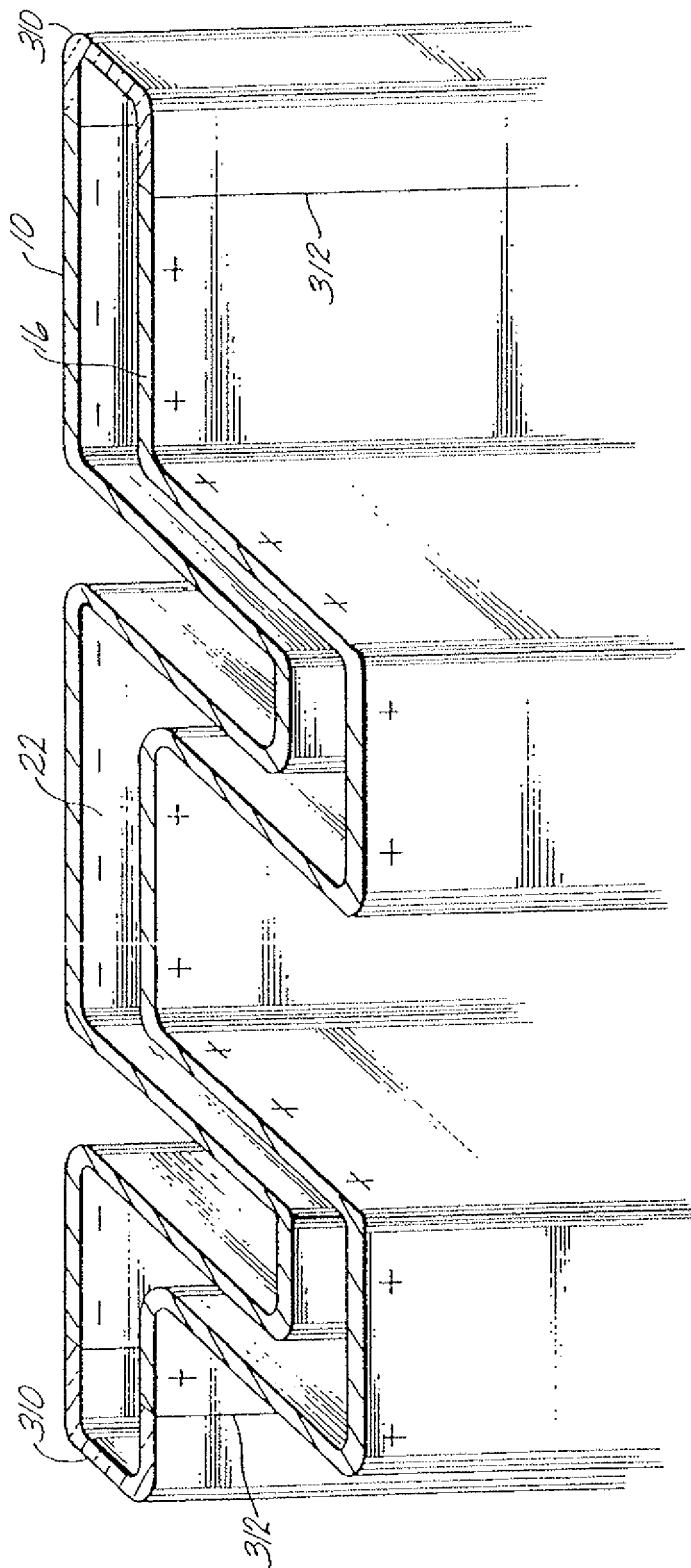
Fig. 1

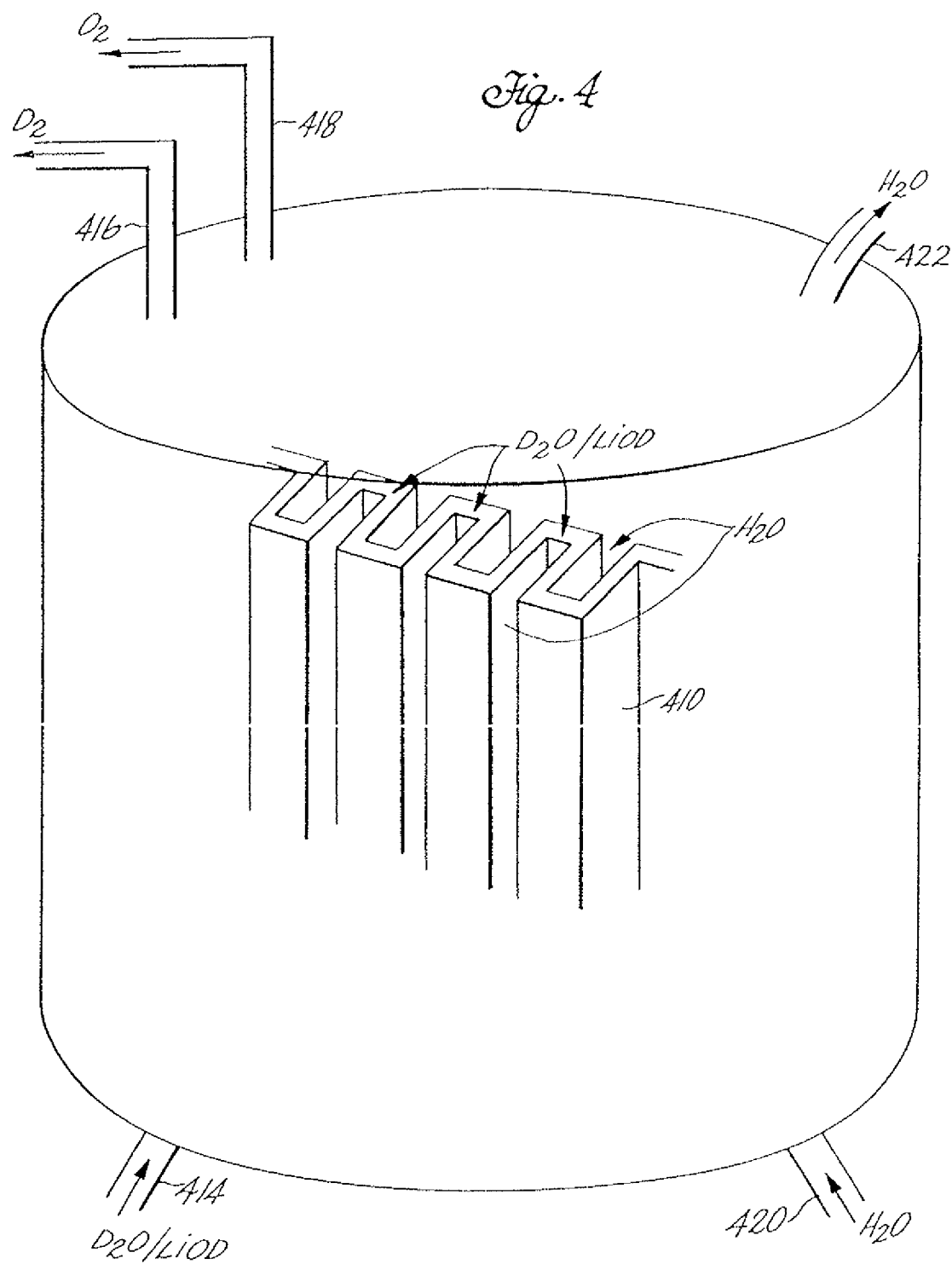




3/8

Fig. 3





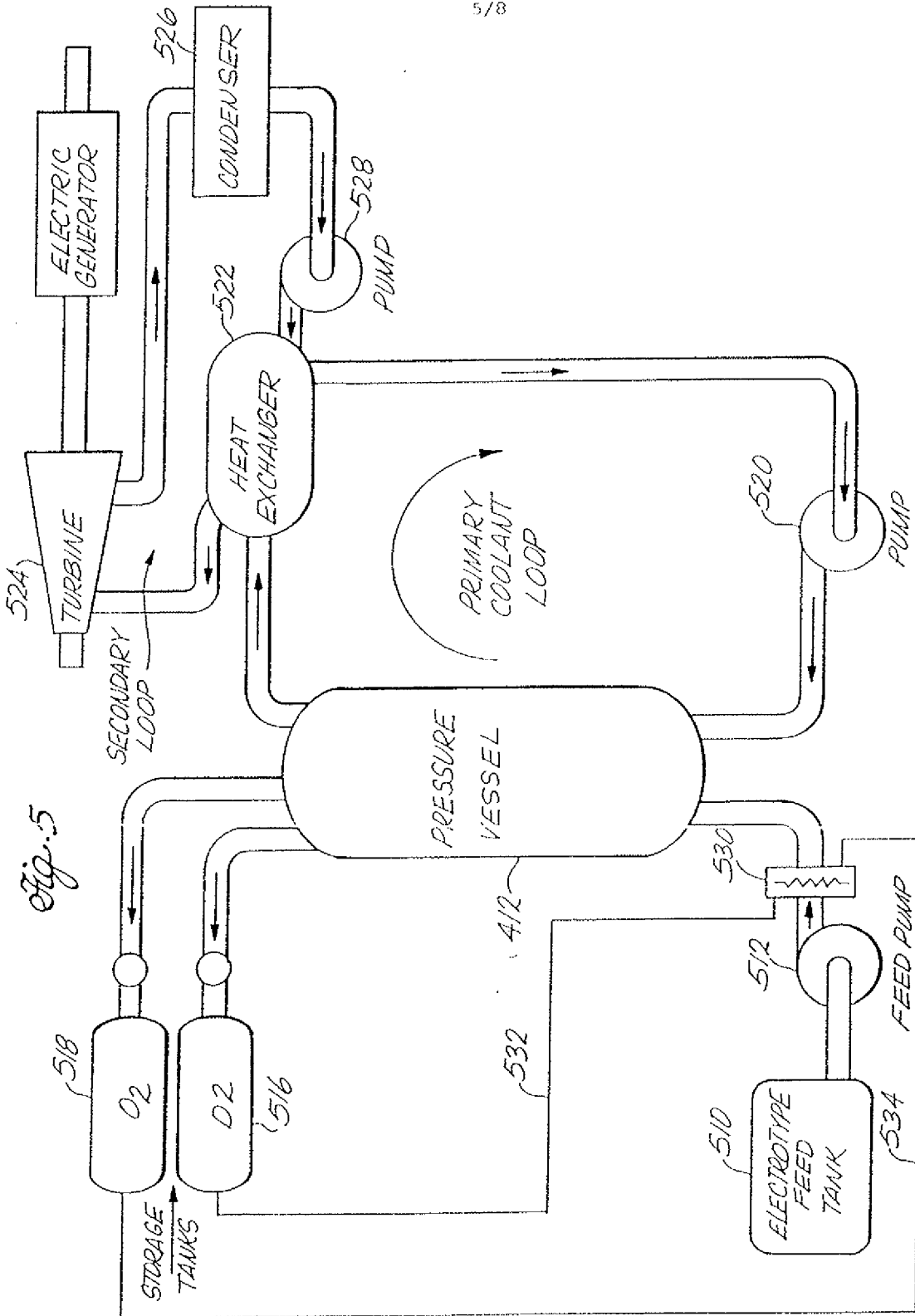


Fig. 6

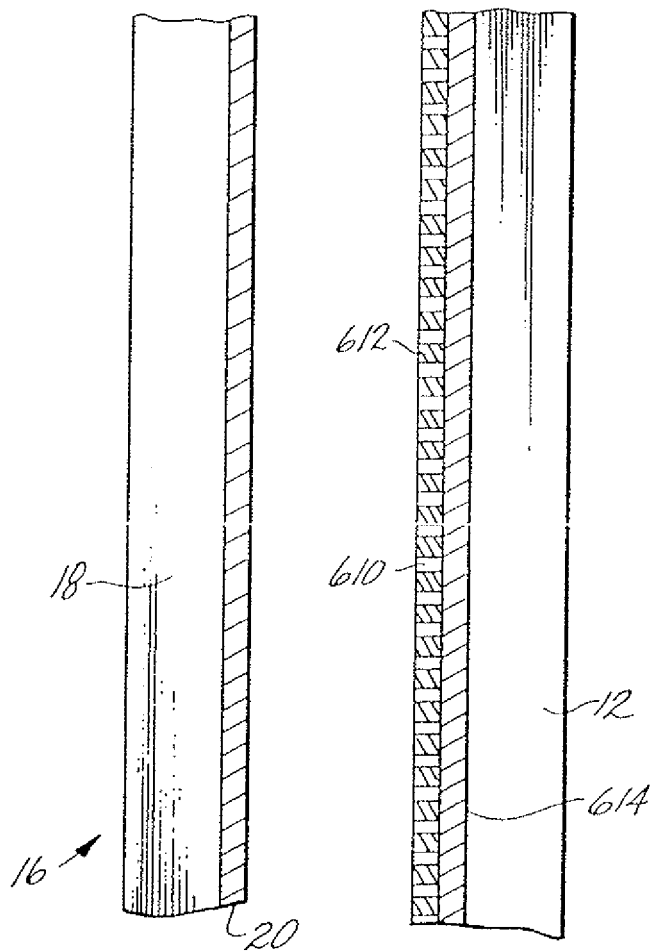
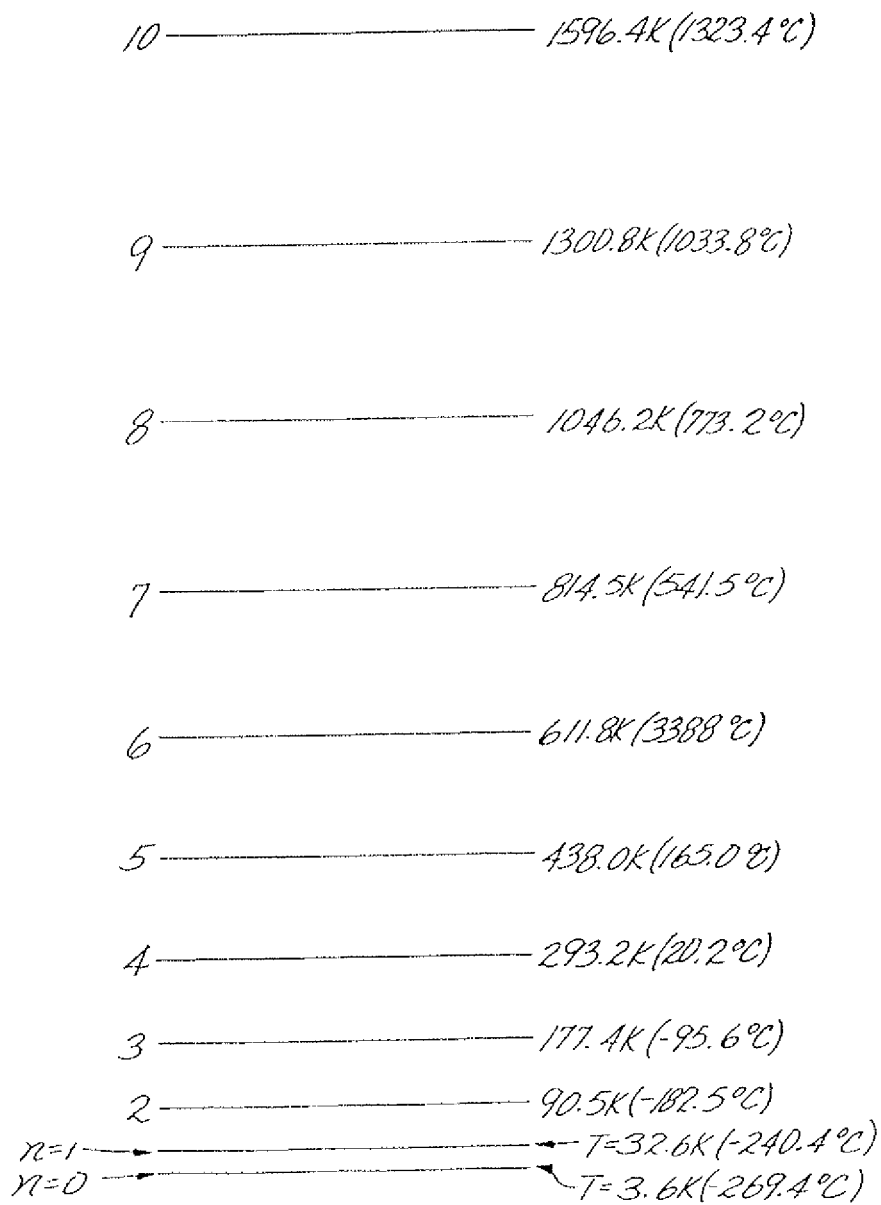
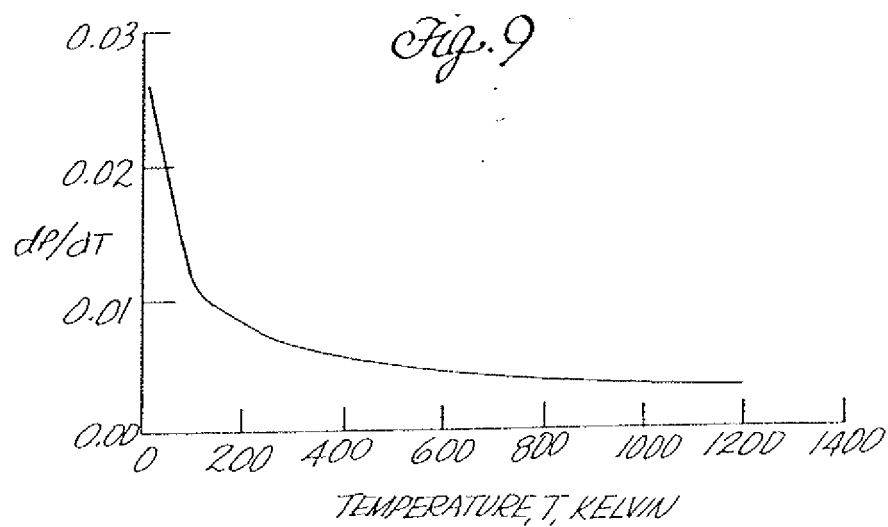
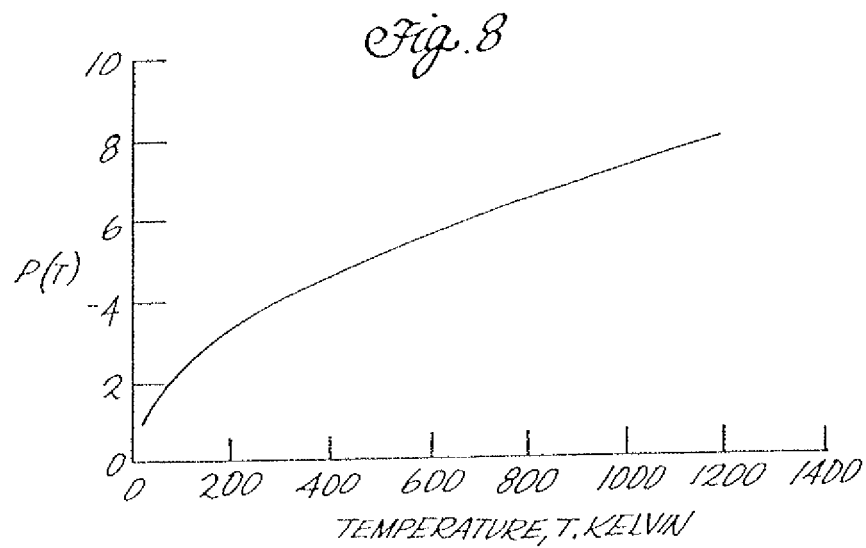


Fig. 7





INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/07073

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC (5): G21B 1/00 U.S.CL.: 376/100		
II. FIELDS SEARCHED		
Minimum Documentation Searched *		
Classification System	Classification Symbols	
U.S.	376/100, 146, 114, 115 423/248, 645, 647.7 420/900, 463, 464, 465 204/129, 290A, 290F, 291, 292, 293, DIG. 8	
Documentation Searched other than Minimum Documentation to the extent that such documents are included in the Fields Searched *		
III. DOCUMENTS CONSIDERED TO BE RELEVANT 1*		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages 1*	Relevant to Claim No. 1*
Y	Electroanalytical Chemistry, Volume 261, No. 2A, page 301-308, Parsons et al., April 1989.	1-22
Y	"The Palladium Hydrogen System", Academic Press 1967, page 1-180, Lewis; Figure 3.3.	2,3,6,12,15
Y	"The Kinetics of Hydrogen Absorption-Desorption by Metal", Pergamon Press 1981, page 329-343, Pick; page 341, Paragraph 2.	2.9,15,22
Y	US, A, 4,663,006 (YAO ET AL) 05 May 1987, Column 10, line 54-57; abstract.	18
Y	US, A, 4,373,176 (FINKELSTEIN ET AL) 08 February 1983; Column 1, lines 44-51.	21
Y	US, A, 3,455,845 (WICKE ET AL) 15 July 1969; Column 1, lines 47-52; column 2, lines 31-42.	5,6,10
Y	"Determination of the Hydrogen Content of Palladium and Palladium Alloys from Measurements of Electrode Potential and Electrical Resistance", Pergamon Press 1963, Volume 10, page 237-246, Barton et al; page 239, Paragraph 5.	10
* Special categories of cited documents: 1* "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "A" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search * 03 APRIL 1991		Date of Mailing of this International Search Report * 29 APR 1991
International Searching Authority ISA/US		Signature of Authorized Officer DANIEL WASIL

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE¹

This International search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out i, specifically:

3. ☐ Claim numbers because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING²

This International Searching Authority found multiple inventions in this international application as follows:

See attachment

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

- ☐ The additional search fees were accompanied by applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

PCT/US90/07073

Continuation of PCT/ISA/210 item VI
"Observations where unity of invention is lacking"

- I. Apparatus for producing heat energy; (claims 1-14).
- II. Method of producing power; (claims 15-21).
- III. Method of creating a cold fusion reaction; (claim 22).

The claims of these groups are directed to different inventions which are not so linked as to form a single general inventive concept. The inventions are not linked in operation and perform completely different operations. Note PCT Rule 13 and 37 CFR 1.475.

Within group I there is lack of unity under PCT Rule 13 between the following independent and distinct species :

- Ia. The embodiment having a polycrystalline cladding; (claims 1-11, 13, 14).
- Ib. The embodiment having dielectric strips bonded intermediate single crystals; (claims 1-4, 7-14).

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, ¹⁴ with indication, where appropriate, of the relevant passages ¹⁵	Relevant to Claim No ¹⁶
L	Nature, volume 344, page 401-405, 29 March 1990, Salamon et al., cited as casting doubt on inducing nuclear fusion in a catalyst by forcing hydrogen isotopes therein.	1-22
L	ORNL/FTR-3341, page 1-17, 31 July 1989, Cooke; Cited as casting doubt on inducing nuclear fusion in a catalyst by forcing hydrogen isotopes therein, see page 3-5.	1-22